NAILSC REPORT 03-41

AD A030787

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Naval
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Integrated
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Center

AN INVESTIGATION OF THE NAVY OIL ANALYSIS PROGRAM (NOAP)

(AS APPLIED TO JET AIRCRAFT ENGINES AND ACCESSORIES)

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Naval Aviation Integrated Logistic
Support Center
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27 May 1976

INTERIM REPORT

Distribution Unlimited

Prepared for:

Naval Aviation Integrated Logistic
Support Center
Patuxent River, Maryland 20670

NAVAL AVIATION INTEGRATED LOGISTIC SUPPORT CENTER

N.A.S. PATUXENT RIVER, MARYLAND 20670

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER: NAILSC REPORT-03-41

2. GOVT ACCESSION NO.

3. RECIPIENT'S CATALOG NUMBER

4. TITLE (and Subtitle): AN INVESTIGATION OF THE NAVY OIL ANALYSIS PROGRAM (NOAP) (As applied to jet aircraft engines and accessories).

5. TYPE OF REPORT & PERIOD COVERED: Interim rept.,

6. PERFORMING ORG. REPORT NUMBER

7. AUTHOR(S): Charles W. Chandler, Jr

8. CONTRACT OR GRANT NUMBER(s)

9. PERFORMING ORGANIZATION NAME AND ADDRESS: Naval Aviation Integrated Logistic Support Center, Patuxent River, Maryland 20670

10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS

11. CONTROLLING OFFICE NAME AND ADDRESS: Naval Aviation Integrated Logistic Support Center, Patuxent River, Maryland 20670

12. REPORT DATE: 27 May 1976

13. NUMBER OF PAGES: 38 pages

14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office): 40p.

15. SECURITY CLASS. (of this report): Unclassified

15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report): Distribution of this document is unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report): Unlimited.

18. SUPPLEMENTARY NOTES: Approved for public release.

19. KEY WORDS (Continue on reverse side if necessary and identify by block number): Spectroscopy, Spectrometric analysis, oil analysis, Ferrograph, Ferrography, engine condition monitoring, jet engine failure prediction, failure prediction, Navy Oil Analysis Program, NOAP, Spectrometric oil analysis, SOAP, mechanical wear mechanisms.

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

An investigation of the current Navy Oil Analysis Program has been conducted with the intent of increasing the efficiency of the program in the prediction of jet engine failure. A comprehensive review of the available literature concerning current oil analysis systems was made in conjunction with interviews of both military and commercial personnel. The conclusion drawn from this evaluation is that the current spectrometric methods

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UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

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AB

20. Abstract (continued)

used by the Navy are capable of effectively determining amount and composition of the contamination particles in lubricating oils; however, this determination is limited to particles under 8 microns (approximately). Also, spectrometric analysis cannot identify the shape, size, or the probable wear mechanism which created the particles. Since catastrophic failures are quite often characterized by the sudden appearance of particles greater than 8 microns, it was evident that some supplemental analysis would be of considerable value. The research conducted indicated that, due to technical and economic reasons, ferrography is the most promising method to supplement spectrometry for oil analysis. (A specific operational example is provided.) The recommendation is to conduct a pilot project to concurrently operate and evaluate a spectrograph and a ferrograph to determine their complementary capabilities.

SUMMARY

1.0 Purpose/Scope. The Advanced Logistic and Systems Evaluation Department (300 Department) of the Naval Aviation Integrated Logistic Support Center (NAILSC) is tasked with the analysis and evaluation of proposed and existing logistics systems which impact, or may impact, fleet operations. The Navy Oil Analysis Program (NOAP) has, as its express purpose, the task of examining oil-wetted components of jet engines and predicting their impending failure. The recent development of a number of systems which have the potential for improving the NOAP has prompted the 300 Department to investigate these systems. The purpose of this investigation is to examine the NOAP with the objective of determining its methods of operation, its capabilities and limitations, and substitutes for, or complements to, the current system; the ultimate goal being recommendations for the improvement of the NOAP. Such improvement would have a significant impact on both safety of flight and fleet readiness as well as the expectation of a reduction in fleet logistic resource requirements.

The scope of this investigation was limited to detailed review of the available literature on the subject of oil analysis and interviews with both civilian and military personnel involved in the oil analysis programs. The information obtained was not limited to spectrometric oil analysis techniques which the Department of Defense currently employs.

This report deals only with the conclusions and recommendations resulting from the analysis of substitutes for and complements to the NOAP. It does not attempt to discuss in any detail the characteristics of all of the oil analysis systems.

2.0 Findings. The findings of this preliminary investigation are presented in paragraphs below as a comparison between the current NOAP method (spectrometric oil analysis) and the most promising complementary method, ferrography:

The following is a comparison of the current NOAP method and ferrography.

a. Spectrometric Oil Analysis Program (SOAP) capabilities:

(1) Identifies specific chemical elements suspended in fluids.

(2) Determines the amounts of the elements in fluids.

(3) Speed and simplicity of operation.

b. SOAP limitations:

(1) Unable to analyze particles larger than approximately eight microns.

(2) Unable to determine size or shape of particles in fluids.

(3) Unable to identify the wear mechanisms which produce particles in fluids.

(4) Lack of standardization in allowable amounts of particles.

c. Ferrographic capabilities:

(1) Analyzes particles from 0.1 to greater than 100 microns in size.

(2) Determines particle size, shape, and density.

(3) Predicts failing parts based on wear mechanisms which produce certain size/shape particles.

d. Ferrographic limitations:

(1) Limited ability to identify particle composition.

(2) Requirement for a trained analyst.

(3) Somewhat slower than the spectrograph.

3.0 Conclusions. As a result of this investigation, it appears that the effectiveness of spectrometric oil analysis could be considerably enhanced with one or more existing techniques as a supplement. One such technique which stood out in the analysis as having the most promise as an aid to spectroscopy was ferrography. Ferrography is a technique which has the capability of measuring the size, density, and shape of particulate matter in engine oil and hydraulic fluids. Other reasons for selecting ferrography over other techniques include its apparent high reliability, relative ease of operation, and reasonable cost. There are also case histories of engines which failed or would have failed catastrophically had it not been for predictions based on ferrographic analysis; the NOAP having previously indicated these engines to be satisfactory.

4.0 Recommendations. In view of the obvious complementary natures of the spectrograph and the ferrograph, it is recommended that a pilot project be conducted to determine quantitatively the capabilities of these two methods, both separately and in conjunction with each other and to determine the problems in implementing such an integrated system. During this experiment the two systems would optimally be co-located with the sampling and testing being conducted concurrently. This arrangement would provide both the required experimental control and the personnel to conduct the experiment.

1.0 INTRODUCTION

The Navy Oil Analysis Program (NOAP) was established on 15 October 1968 by Secretary of the Navy (SECNAV) Instruction 4730.1. The creation of this program was the result of the initiation of the Spectrometric Oil Analysis Program (SOAP) by the Navy at Pensacola, Florida and an ultimate Tri-Service Agreement (Naval Air Systems Command (NAVAIR) Instruction 4730.1 dated 6 March 1967) to implement a Joint Oil Analysis Program (JOAP). The goals of the NOAP are to achieve optimum utilization and standardization of oil analysis equipment within the Navy and the Department of Defense and to improve laboratory techniques and locations for interservice use. The Chief of Naval Material (NAVMAT) was assigned the responsibility (Chief of Naval Operations (OPNAV) Instruction 4730.6) for administering the program, while fleet direction as to its implementation and use is provided by NAVMAT Instruction 4731.1 and OPNAV Instruction 4790.2A (CH-2). The Navy program now encompasses 38 oil analysis laboratories world-wide. This program monitors almost every Navy-owned jet engine and its accessories (as well as some hydraulic systems) and involves a considerable number of personnel.

The magnitude of this program and its ultimate impact on naval aviation safety and logistics has prompted an investigation of the technical operation of spectrometric oil analysis as applied to jet engines, the effectiveness of this application, and possible innovations which could supplement the current NOAP. It is anticipated that improvements to this program would also have a significant impact on improving aircraft readiness and flight safety as well as fleet logistics. The approach to this investigation and its determinations, conclusions, and recommendations are presented in the following paragraphs.

2.0 APPROACH

The initial approach to this investigation was an individual effort to identify, obtain, and review the available literature concerning oil analysis without discrimination as to the origin of the material. As a result, information was obtained from military and commercial services, both national and foreign. The next step was to contact personnel who are currently involved with oil analysis. The purpose of these contacts was to develop an understanding of spectrometric oil analysis and, in particular, the Navy applications of this technique. The final phase of the investigation was an assessment of other oil analysis techniques which are being, or could be, used to supplement spectrometric techniques.

3.0 TECHNICAL FINDINGS

3.1 Spectrometric Oil Analysis

Spectrometric oil analysis is a non-destructive testing technique used to determine the internal condition of fluid-lubricated mechanical systems. It has the capability of precisely determining which foreign elements the lubricant carries and the concentration of these contaminants in terms of parts per million (ppm). The premise here is that as the internal surfaces of a machine wear as a result of normal contact, introduction of external particles in the lubricant, fatigue or other reasons, wear particles will be generated. The amounts of these particles and their generation are assumed to be indicative of the approach of failure of the machine. The identification of the composition of these particles as iron, silver, lead, etc., is used to assist in finding the part which is failing. This theory appears to hold for the types of wear which produce a gradual build-up of small (less than 5 microns) particles. This type of wear is typical of the normal operation of two well-lubricated sliding surfaces. However, there are a number of other wear mechanisms which produce particles larger than 5 microns at a very fast rate. When this occurs, a catastrophic failure is usually imminent.

Spectrometric analysis, being limited to the investigation of particles of less than approximately 8 microns, cannot detect the larger wear particles and thus is limited in its ability to predict impending failures. Accepting this limitation and considering the very accurate (0.5 ppm) capability of the spectrograph to identify the normal rate of wear of a machine, spectrometric oil analysis can be used quite effectively to determine the overhaul limits of the equipment as well as monitor its internal condition.

3.2 Supplementary Techniques

Due to the limitation of the spectrograph's ability to analyze particles above approximately 8 microns, other devices must be used as supplements in order to provide the necessary prediction capability. A number of experiments have been made to this end with varying degress of success. These experiments include collectors for magnetic chips, magnetic chip indicators, oil filter analysis, in-line x-ray techniques, in-line measurements of the attenuation of light, atomic fluorescense, colorimetric methods, and ferrography. The available literature on these techniques was reviewed to determine their capability to supplement spectrometry. With the exception of ferrography, these systems appear to be too costly or too impractical to install, are unreliable, or provide failure indications too late to prevent major damage.

3.3 Ferrography

Of these systems, only the ferrograph stood out as being a practical means of expanding the capabilities of SOAP. Ferrography is a relatively new technique which measures the attenuation of light in the fluid sample to determine the density or extent of contamination. It also has a high gradient magnetic field to align the particles according to size on a microscope slide and a Bichromatic microscope to determine the nature and origin of the particles. The major characteristics of ferrography which indicate that it could be a very useful addition to the NOAP are its ability to "see" large particles (which the spectrograph would miss) as well as particles down to 0.1 micron in size and its capability to determine the shape of the particles.

3.4 Wear Mechanisms

The shape of wear particles is particularly important, since most failure modes have a wear mechanism which produces characteristically-shaped particles. (For example, a failing ball bearing will generate a considerable number of microscopic spheres.) By examining these particles, a trained operator can diagnose the part which is failing.

The density of the wear debris is used to determine the trend toward failure. As a part approaches total failure, more and more particles are generated and their concentration can be measured. Any sudden increase in this density is an indication of impending failure. (Gradual increases are most often the result of normal wear and the "problem" can be solved by changing the oil and filters, although SOAP might indicate that the equipment was failing.)

3.5 NOAP vs Ferrograph Example

One very specific example of the use of the ferrograph to supplement the NOAP is shown in appendix A. In this case, the Systems Engineering Test Directorate (SETD) of the Naval Air Test Center (NATC), Patuxent River, Maryland was using ferrographic techniques to monitor a J52-P-408 engine. The engine was also being routinely monitored by the NOAP. Table 1 shows the oil analysis history for this engine as analyzed at Andrews Air Force Base, Maryland. Note that the concentrations vary only slightly and the iron readings are well below the 19 ppm danger limit. Table 2 gives the ferrograph history of the engine oil. The persistent and drastic increase in large particles was the reason for grounding this engine.

ANDREWS AFB SOAP HISTORY, J52-P-408 SER. NO. 678301

SAMPLE DATE	HOURS SINCE OVERHAUL	HOURS SINCE OIL CHANGE	PARTS PER MILLION (PPM) AL	FE	CR	MG	CU
9/ 5/5	349	54	0	5	1	3	1
22/ 5/5	358	63	0	6	1	4	1
08/ 5/5	367	72	0	5	0	4	1
24/ 6/5	376	81	0	6	1	5	1
30/ 6/5	389	94	0	7	1	0	1
15/ 6/5	398	103	0	6	1	5	1
21/ 8/5	423	128	0	7	1	6	0
26/ 8/5	440	145	0	6	1	1	0
30/ 8/5	450	155	0	7	2	6	1
11/ 9/5	455	160	0	7	2	5	1
26/ 9/5	464	169	0	7	1	5	0
6/10/5	468	173	0	8	2	5	1
LIMITS			7	19	—	9	9

TABLE 1

ANDREWS AFB SOAP HISTORY, J52-P-408 SER. NO. 678301

SAMPLE	HOURS SINCE		PARTS PER MILLION (PPM)				
DATE	OVERHAUL	OIL CHANGE	AL	FE	CR	MG	CU
7/10/5	470	2	0	2	0	2	0
16/10/5	485	17	0	4	0	2	0
1/11/5	498	30	0	3	0	2	0
7/11/5	514	46	0	3	1	2	0
20/11/5	530	62	0	4	1	2	0
25/11/5	540	72	0	5	1	2	0
26/11/5	544	76	0	5	1	2	0
01/12/5	546	.5	0	2	0	1	0
01/12/5	546	78	0	5	1	2	1
02/12/5	548	2	0	1	0	0	0
03/12/5	549	3	0	1	0	1	0
04/12/5	555	9	0	1	0	1	0
LIMITS			7	19	___	9	9

TABLE 1 (CON'D)

ANDREWS AFB SOAP HISTORY, J52-P-408 SER. NO. 678301

SAMPLE DATE	HOURS SINCE OVERHAUL	HOURS SINCE OIL CHANGE	PARTS PER MILLION (PPM) AL	FE	CR	MG	CU
05/12/5	557	11	0	2	0	1	0
05/12/5	558	12	0	2	0	1	0
05/12/5	560	14	0	2	0	1	0
05/12/5	563	17	0	2	0	1	0
06/12/5	565	19	0	3	0	1	0
06/12/5	567	21	0	3	0	1	0
08/12/5	569	23	0	2	1	0	0
10/12/5	571	25	0	3	0	1	0
10/12/5	575	29	0	3	0	1	0
11/12/5	579	33	0	3	1	0	1
16/12/5	589	43	0	4	1	1	0
15/12/5	587	41	0	3	0	0	0
LIMITS			7	19	___	9	9

TABLE 1 (CON'D)

FERROGRAPHIC HISTORY, J52-P-408 SER. NO. 678301

DATE	HOURS SINCE OVERHAUL	HOURS SINCE OIL CHANGE	PARTICLE DENSITY LARGE	PARTICLE DENSITY SMALL	SAMPLE #	REMARKS
8/22/75	423	128	1.8	2.5	1	*1
9/12/75	455	160	6.8	3.9	4	*1
10/10/75	470	2	5.0	1.7	5	*2
12/ 2/75	545	73	6.5	6.1	11	*1
12/ 2/75	546.5	0.5	4.3	.8	12	*2
12/ 9/75	569	23	3.4	.8		
12/10/75	571	25	4.2	1.0		
12/10/75	575	29	3.1	1.9		
12/14/75	579	33	7.1	2.4		
12/15/75	587	41	100.7	6.8		*3
12/16/75	588	1	13.9	10.8	28	

*1 OIL DARK

*2 OIL CHANGED

*3 AIRCRAFT GROUNDED FOR ENGINE REMOVAL

TABLE 2

NARF JAX SOAP READINGS, J52-P-408 SER. NO. 678301

SAMPLE DATE	PARTS PER MILLION (PPM)			
	FE	AL	CR	MG
1/29/76	003	000	000	000
3/ 2/76	003	000	000	000
3/ 2/76	002	000	000	000
3/ 2/76	003	000	000	000
3/ 2/76	003	000	000	000
3/ 2/76	003	000	000	000

TABLE 3

Table 3 is the result of analysis of oil samples taken from the engine at Naval Air Rework Facility (NARF) Jacksonville, Florida. The fact that the values are considerably different at the two laboratories is also of interest, although both readings are regarded as normal. This difference may be due to the fact that the procedures at one laboratory are automated while the other employs a manual operation.

After several iterations of watching the particle density index increase drastically even after oil changes, the aircraft was grounded and the engine was removed and sent to NARF Jacksonville for disassembly and inspection. The ensuing engineering investigation revealed three oil pumps and two bearings in obvious phases of failure. Complete failure of one of the bearing was imminent. However, despite the enormous amount of internal damage to this engine, the NOAP did not indicate any abnormality in the engine oil. Photographs of the wear particles deposited on a ferrograph were taken through the Bichromatic microscope and are shown in appendix B. These pictures shown some of the classic wear particles which were found in the oil of this engine. An example of particle density on a ferrograph slide is shown in appendix C.

As a result of the success in the above example, the NATC in-house program has been expanded to monitor other engines and associated components with apparently equal success. Other programs which have experimented with the ferrograph as a maintenance tool are the Surface Effects Ship project at NATC (which includes both hydraulic fluid and engine oil), the Naval Ship Engineering Center, and the Department of the Air Force. A number of commercial concerns are also using the ferrograph, as are several universities. These include Pratt and Whitney Aircraft Corporation, Oklahoma State University, and the National Engineering Laboratory in Scotland.

3.6 Data Collection/Analysis

During the course of the investigation of oil analysis techniques, an attempt was made to obtain definitive data concerning the operational effectiveness of both SOAP and the ferrograph. This effort was unsuccessful due in part to the newness of the ferrograph and, until recently, to the lack of record-keeping for either system. This problem will be partially alleviated with the implementation of the JOAP data collection system; however, this system will not include information from the ferrograph readings. Because of this lack of data, it has been impossible to quantitatively evaluate either system with any reasonable confidence in the results. Some of the few recorded statistics which were found are reported below:

a. In 1970, a Naval Air Technical Services Facility (NATSF) report provided information concerning 464 aircraft engines which were disassembled and reported on by rework activities during the six-month period ending December 1969. These engines had been removed from service due to metal contaminated oil systems discovered through maintenance inspection or chip detector systems. A total of 134 engines (28.9 percent) in this group were being monitored by spectrometric oil analysis, although their removal was not related to this analysis. This report also notes that 40 of 53 (75.4 percent) of the gas turbine engines removed because of spectrometric oil analysis indications disclosed positive indications of failure at disassembly.

b. One airline reported that a spectrographic test of nearly 1,000 samples found only a few typical failures. The conclusion was drawn that failure detection devices should include some form of filter or chip detector.

c. In 1968, the Navy reported a 90 percent success rate (justified removals due to SOAP indications) on jet engines. The total number of removals was not given.

d. In 1971, the Air Force reported a 95 percent success with no details given.

e. In a survey of 23 airlines, 11 use SOAP. Of the 12 which which did not, six had tried and dropped the program. The reasons for discontinuance included logistic problems with oil samples, no failures of bearings, uneconomical operation, unsubstantiated SOAP removals, magnetic chip detectors identify majority of bearing failures, and additional personnel required.

4.0 CONCLUSIONS

As a result of the investigation conducted to date concerning oil analysis techniques and results, it is evident that the spectrograph requires some supplemental technique in order to provide an effective program for failure prediction.

4.1 The complementary characteristics of the ferrograph to those of the spectrograph makes the combination of the two systems a logical approach to improving the capabilities of the Navy Oil Analysis Program.

4.2 The lack of conclusive data concerning either system indicates that, before implementation of this approach, a pilot project should be conducted to determine precisely the capabilities and problems associated with combining the two systems.

5.0 RECOMMENDATIONS

In order to evaluate the ability of the ferrograph to supplement the NOAP, the following approaches are suggested:

5.1 The evaluation of the two systems must be conducted in a reasonably-controlled experiment with oil samples being analyzed concurrently by both the spectrometer and the ferrograph. In order to ensure this concurrency and the timeliness and accuracy of data collection, it is recommended that the two machines be co-located. To satisfy this control requirement, a spectrograph of the type most commonly used by the NOAP laboratories could be obtained and bailed to the Naval Aviation Integrated Logistic Support Center (NAILSC). This equipment would be located in the Ferrographic Laboratory of the Systems Engineering Test Directorate at NATC, Patuxent River, Maryland. The oil samples from all aircraft located at NAS Patuxent River and the NATC would be analyzed both with the spectrometer and the ferrograph. The analysis and data collection would be a joint NAILSC/SETD effort.

5.2 An alternative to the above would be to buy or lease a ferrograph and locate it at one of the existing NOAP laboratories. The major drawback here would be the training of an additional person to operate the ferrograph and analyze its results.

The data to be collected and analyzed in either of the above procedures would be the particle count and element definition given by the spectrograph and the particle density and description from the ferrograph, along with engine operation and maintenance history. From this information, a conclusion can be drawn as to the effectiveness of combining the capabilities of the two systems. The samples to be analyzed would be the standard NOAP samples taken at the current required intervals from both engines and associated equipment (gearboxes, transmissions, etc.).

APPENDIX A

FERROGRAPHIC AND SPECTROGRAPHIC DATA

The data presented in this appendix are actual figures concerning the history of a failing J52-P-408 engine being monitored at NAS Patuxent River, Maryland. Exhibit A-1 is the report of the disassembly and inspection of the engine at NARF Jacksonville, Florida. Exhibit A-2 is the NOAP record for the engine as determined at Andrews Air Force Base, Maryland. Exhibit A-3 gives the ferrographic history of the engine.

STRIKE MAINTENANCE NATC, US NAS PATUXENT RIVER, MD	NAVAIRENGRFAC JAX FL	5B37	2-17-76

☐ AIRCRAFT	☐ MISSILES	☐ MECHANICAL COMPONENTS	☐ PECULIAR GSE	☐ NO DISCREPANCY	☐ MAINTENANCE/ OPERATING DISCREPANCY
☒ ENGINE	☐ ELECTRICAL AVIONICS	☐ COMMON GSE	☐ OTHER	☐ MFG DESIGN DISCREPANCY	☐ FOREIGN OBJECT DAMAGE

9 ASSEMBLY WORK UNIT CODE	10 ASSEMBLY NOMENCLATURE AND PART NUMBER	11 ASSEMBLY MODEL	12 ASSEMBLY SERIAL NUMBER	13 ASSEMBLY MANUFACTURE
23500	Turbojet Engine	J52-P408	678301	77445

14 REPORTED FROM	15 REPORTED FROM	16 REPORTED FROM	17 TOTAL HOURS SINCE NEW	18 HOURS SINCE LAST OVERHAUL
			591	NA

19 NO. OF PREV. OVERHAULS	20 DATE LAST OVERHAUL	21 LAST REWORK FACILITY	22 AIRCRAFT MODEL	23 AIRCRAFT BUREAU NUMBER
NA	NA	NA	A-4M	158148

24 REPORTING ACTIVITY (LOCATION)	25 PRIMARY PART FAILURE AUC	MAC	PART NUMBER	NOMENCLATURE
STRIKE MAINTENANCE NATC, US NAS PATUXENT RIVER, MD	23582	020	679698	Main Oil Pump Assembly

26 DISCREPANT PART NUMBERS	27 PERTINENT TECHNICAL MANUALS, BULLETINS, CHANGES ETC NUMBER	COMMENT

28 DESCRIPTION OF DISCREPANCY (Attach additional sheets if required)

SEE REVERSE SIDE

Encl: (1) Oil Analysis Record NARFP 13710/957(Rev. 10-73)
J52-P408 S/N 678301 6029 Pre-induction (PI)

29 CONCLUSION

30 RECOMMENDATIONS

31 REFERENCES (Other than Engineering Survey)		32 INVESTIGATION COMPLETED
(a) NAVAIRTESTCEN PAX RIV, 192359Z DEC 75		JAX-J52-214-50
33 SIGNATURE	34 TITLE	35 DATE SIGNED
J. C. OSTERTAG	ACFT & ENGINES ANALYSIS BRANCH SUPV (Code 433)	2-20-76

36 COPY TO
NATC PAX RIV (CODE SA-62) Attn. Mr. Thomas
" " " (CODE SA-42) Attn. Mr. Hilleto

EXHIBIT A-1

INVESTIGATOR [illegible] C. R. COOKS AVN 942-2455/2166

NAVAIREWORKFAC JAX DIR S/N 5B37 OF 12 FEBRUARY 1976 (CONTINUED)

26. DESCRIPTION OF FINDINGS:

An engineering investigation was conducted on this engine in accordance with reference (a) request in the presence of Messrs. Thomas and Mileto, NATC PAX RIV Representatives. The engine had been removed as a precautionary measure and an engineering analysis requested to assist in establishing the credibility of the Ferrograph System Technique presently being monitored at NATC. Routine ten hour NOAP oil samples has revealed no abnormal conditions. However, the NATC prototype Ferrograph System of Engine Oil Monitoring indicated a rapid rise in large particles. (Steel and Aluminum). Prior to engine removal the oil had been changed to conduct further testing. NOAP Lab Tests of oil samples taken upon receipt of engine at NARF JAX revealed no abnormality. Enclosure (1) refers. There was no visible metal in the main oil strainer. Light metal contamination was visible in the oil throughout the system. The inside of the main oil pump, P/N 679698, was worn and scored as follows: The side wall of the spur drive gear cavity in the inner body, P/N 597474, exhibited severe, one-sided wear and scoring. The idler gear cavity side wall was lightly scored. Both cavity side walls of the outer body (scavenge side), P/N 538826, were lightly scored. The drive spur gear, P/N 505827, was lightly scored on both journals and severely scored on the impeller vane edges. The idler spur gears, P/N 389726, and P/N 334714, and the drive spur gear, P/N 538827, were lightly scored on the impeller vane edges.

The No. 4. and 5. bearing oil scavenge pump, P/N 540138, was heavily chafed and scored as follows: The spur drive gearshaft, P/N 466850, idler gearshaft, P/N 366365, drive spur gear, P/N 313742 idler spur gear, P/N 379104, were scored and had metal buildup on the impeller vane edges. The cavity side walls of the housings P/N 400378 and P/N 316737, were severely chafed and scored. The drive splines of the spur drive gearshaft, P/N 466850 and the mating drive gear, P/N 446852, were grooved and had metal pile up, apparently from force during installation due to tight fit or misalignment.

The No. 6. bearing scavenge pump, P/N 581180, had a very few light scratches in the housing cavity side walls. However, the spur drive gearshaft, P/N 442076, journals and impeller vane faces and edges were scored. The mating spur idler gear impeller vane faces and edges were also scored and one vane on both of the gears was overheat discolored.

Removal, disassembly and examination of all of the engine and accessory gear box bearing revealed that the No. 4 1/2 bearing, P/N 493783, and the No. 5. bearing, P/N 363169, were damaged beyond use. All others showed superficial damage which was within limits. The No. 4 1/2 bearing rollers and raceways exhibited scoring and metal impregnation. Light scuffing on the inner surface of the inner race indicated creeping. The No. 5. bearing components were overheat discolored but within the Rockwell hardness requirement of C-61. The functional surfaces of the rollers and races exhibited scoring and metal impregnation. Witness marks on the surface of the

inner race indicated that the bearing had been operating in an alternately loaded and unloaded condition. The surface roughness of the inner raceway was 8 - 10 RMS the requirement is 10 RMS Max. The surface roughness of 5 rollers based on 3 traces, each, taken at instrument cutoff of 0.030 inch was, 2 rollers 15 - 30 RMS, 2 rollers 7 - 12 RMS and 1 roller 10 - 20 RMS. The surface roughness of rollers taken from new bearing was 9 - 14 RMS. The roller surface requirement is not provided on the PWA drawing no. 363169.

Scanning Electron Microscope (SEM) pictures of the damage to the oil pumps were provided to the NATC REPS, upon request, for further study.

27. CONCLUSIONS:

The reported metal contamination of the oil system resulted from failure of the main oil pump due to misalignment of the drive spur gear-shaft. This is a known type failure under investigation. (PSP) item No. E-25 refers. All other damage noted in the oil system was subsequent and due to the main oil pump failure. Failure of the No. 5. main bearing was imminent. The cause of the alternately loaded and unloaded indications on the inner surface of the inner race could not be determined. However the bearing P/N 363169 was provided for use in the J52-P6A engine and was replaced by bearing, P/N 624614, which is optional in the P-408 engine. Justifiable use of bearing, P/N 363169, in the P-408, could not be confirmed. This may contribute to bearing distress.

28. RECOMMENDATIONS:

None.

Copy to:
NAVAIRSYSCOM (AIR-4145/5361/41131/06)
NAVAIRSYSCOMREPLANT (ASCR-3361/2125)
NAVSAFECEN (Code 123)
NAVWESA (Code ESA-4)
NADC (Code 3021)
COMNAVAIRLANT (Code 527)
COMNAVAIRPAC
CNATRA (Code 512)
NAVAIREWORKFAC PNCLA (Code 347)
NAVAIREWORKFAC ALAMEDA
NAVPRO E. Hartford CT
CHNAVRES

OIL ANALYSIS RECORD
NARFP 13710/357 (REV. 10-

EQUIPMENT MODEL	EQUIPMENT SERIAL NUMBER	JULIAN DATE	CUST SERV	CUSTOMER UIC	TYPE INSTP	TYPE ANAL	LAB	END ITEM MODEL	END ITEM SERIAL NUMBER	TYPE OIL
3521403	678301	6003								

CUSTOMER SAMPLE NUMBER	DATA INDEX	JULIAN DATE SAMPLE ANAL	DAYS IN TRANS	DAYS LAB ADV	HOURS MILES SINCE OVHL	HOURS MILES SINCE OIL CHG	REASON FOR SMPL	SPECTROMETRIC ANALYSIS Fe	Ag	Al	Be	Cr	Cu	Mg	Na	Ni	Pb	Si	Sn	Ti	B	Ba	Cd	Mn	Mo	V	Zn	VALIDATION	LAB ADVICE	MAINT ACTION	DISCREP ITEM	HOW MAL
	2	6029	0	0	0591	UNK	R	003	000	000	000	000	000	000	000	000	000	005	005	000	000	000	001	000	000	000	000	B					
	2	6034	0	0			R	003	000	000	000	000	000	000	000	000	000	003	009	000	000	000	001	000	000	000	000	B					
	2	6034	0	0			R	002	000	000	000	000	000	000	000	000	000	003	007	000	000	000	001	000	000	000	000	B					
	2	6034	0	0				003	000	000	000	000	000	000	000	000	000	003	007	000	000	000	002	000	000	000	000	B					
	2	6034	0	0			R	003	000	000	000	000	000	000	000	000	000	003	007	000	000	000	002	000	000	000	000	B					
	2	6034	0	0			R	003	000	000	000	000	000	000	000	000	000	003	006	000	000	000	002	000	000	000	000	B					

EXHIBIT A-1 (continued)

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J52-404 678301 A-4M. 15 8148 STRIKE

BASE

SAMPLING INTERVAL
NUMBER OF OVERHAULS
LAST BRA

BASE SAMPLE NO	LAB TEST NO	CODE	DATE SAMPLE TAKEN	DAYS IN BOUTS	HOURS SINCE O/H	HOURS SINCE O/C	SPECIAL INFORMATION	Al	Fe	Cr	Ag	Cu	Sn	Mg	Si ~~Pb~~	Ni	Ti ~~Sr~~	LAB REQUEST
[illegible]	[illegible]	[illegible]	[illegible]		347	54	[illegible]	[illegible]	3	1	0	1		3	[illegible]			[illegible]
[illegible]	[illegible]	[illegible]	[illegible]		368	13	[illegible]	0	[illegible]	1	[illegible]	1		[illegible]	10	[illegible]	[illegible]	[illegible]
	[illegible]	[illegible]	[illegible]		367	72	[illegible]	[illegible]	[illegible]	0	0	1		[illegible]	[illegible]	[illegible]	1	[illegible]
[illegible]	[illegible]		[illegible]		[illegible]	[illegible]	[illegible]	0	[illegible]	1	0	1		5	[illegible]	1		[illegible]
[illegible]	[illegible]		[illegible]		[illegible]	[illegible]	[illegible]	0	7	1	0	1		0		0		
			[illegible]		398	103	[illegible]	0	6	1	0	1		[illegible]		[illegible]		
[illegible]			21/8		423	128	[illegible]	0	7	1	0	0		[illegible]				
	[illegible]		26/8		440	145	[illegible]	[illegible]	6	[illegible]		[illegible]		[illegible]		1	[illegible]	
	[illegible]		20/8		450	155	[illegible]	0	7	2	1	1		6		[illegible]		[illegible]
[illegible]	710	P	11-9-5		[illegible]	160	[illegible]	0	[illegible]	2	0	1		5		1	[illegible]	[illegible]
[illegible]	675	R	26-9-5		464	169	[illegible]	0	7	1	0	0		5		[illegible]	1	[illegible]
	[illegible]		[illegible]		466	[illegible]	[illegible]	[illegible]	[illegible]	2	0	1		5		1	[illegible]	
	[illegible]		[illegible]		[illegible]	2	[illegible]	[illegible]	2	[illegible]	1	[illegible]		2				
	[illegible]		[illegible]		[illegible]	[illegible]	[illegible]	0	4	1	0	0		[illegible]		[illegible]	1	
	[illegible]	[illegible]	[illegible]		498	20	[illegible]	0	3	0	0	[illegible]		[illegible]		[illegible]		
	[illegible]	[illegible]	[illegible]		514	[illegible]	[illegible]	0	3	1	0	0		[illegible]		[illegible]		[illegible]
	[illegible]	[illegible]	[illegible]		[illegible]	62	[illegible]	0	4	1	0	0		0		1	[illegible]	[illegible]
[illegible]	[illegible]		[illegible]		540	72	[illegible]	0	5	1	0	0		2		0	0	[illegible]
	110	B	21-11-5		544	76			5	1	[illegible]	2		2		1		[illegible]
[illegible]	117	R	01-12-5		546	85	Heavy	0	2	0	0	0		1		1	[illegible]	
[illegible]	121	B	[illegible]		[illegible]	90	[illegible]	0	5	1	0	1		0		1	1	[illegible]
	[illegible]	R	[illegible]		548	2	[illegible]	0	1	[illegible]	0	0		0		[illegible]	[illegible]	[illegible]

REMARKS:

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EXHIBIT
A-6

T5-1	678301	4M	158144	STRIKE PAX RIV.	SAMPLING INTERVAL / NUMBER OF OVERHAULS / LAST SRA

BASE SAMPLE NO	LAB TEST NO	CODE	DATE	ROUTINE	HOURS SINCE O/H	HOURS SINCE O/C	SPECIAL INFORMATION	Al	Fe	Cr	Ag	Cu	Sn	Mg	Pb	Ni	Ti	LAB REQUEST
1695	320	R	3-12-[illegible]		549	3		0	1	0	0	0		1	1	1	1	A
[illegible]	2x1	R	4/12/5		555	9		0	2	0	0	0		1	0	0	1	A
[illegible]	[illegible]	R	5/2/5		557	11		0	2	0	0	0		1		0	1	A
[illegible]	[illegible]	R	5/2/5		558	12		0	2	0	0	0		1		0	1	A
[illegible]	[illegible]	R	5/2/5		561	14		0	2	0	0	0		1		0	1	A
[illegible]	[illegible]		5/2/5		563	17		0	2	0	0	0		1		0	1	A
[illegible]	585	R	[illegible]		566	19		0	3	0	0	0		1		0	1	A
[illegible]	[illegible]	R	[illegible]		567	21		0	3	0	0	0		1		0	1	A
[illegible]	19		8/2/5		569	23		0	2	1	1	0		1		1	1	A
[illegible]	136	R	10/2/5		571	25		0	3	0	0	0		1		1	1	A
[illegible]	737	R	10/2/5		575	29		0	3	0	0	0		1		1	1	A
[illegible]	883	R	11/2/5		579	33		0	3	1	0	1		0		1	1	A
[illegible]	10	R	10-2-5		581	43		0	4	1	1	0		1		2	1	A
	1108	R	15/12/5		587	41		0	3	0	0	0		0		1	1	A

REMARKS

COPY AVAILABLE TO DDC DOES NOT PERMIT FULLY LEGIBLE PRODUCTION

EXHIBIT A-2

C O P Y

RTTEZYUW RUEBRDA444Ø Ø772144Ø-EEEE--RULSSAA RUEDAEA RUEOMKA
RUEOALA.
ZNY EEEEE ORIG: CAPT L W SMITH
R 172ØØØZ MAR 76 REL: CAPT C J BERTHE JR
FM NAVAIRTESTCEN PATUXENT RIVER MD
TO RULSSAA/COMNAVAIRSYSCOM WASHINGTON DC
INFO RUEDABA/NAVAIREWORKFAC JACKSONVILLE FL
RUEOMKA/NAVAIRENGCEN LAKEHURST NJ
RUEOALA/NAVSAFECEN NORFOLK VA
ZEM/NAS PATUXENT RIVER MD
BT
UNCLAS E F T O //N1372Ø//
CNASC FOR AIR-5364, 5361, 51Ø, 62ØC7, 34ØE, 4115C; NAVAIRENGCEN
FOR CODE 92724; NAVSAFECEN FOR CODE 123
FERROGRAPH OIL ANALYSIS OF J52-P-4Ø8 ENGINE S/N 6783Ø1
A. NAVAIRTESTCEN PATUXENT RIVER MD 192359Z DEC 75
B. NARFJAX DISASSEMBLY AND INSP RPT SER NO. 5837 OF 17 FEB 76
1. NAVAIRTESTCEN HAS BEEN USING THE FERROGRAPH OIL ANALYZER MANUFACTURED BY TRANSONICS, INC., SINCE AUG 75 TO MONITOR OIL SAMPLES FROM SEVERAL TEST ENGINES AND ACCESSORIES. THIS PROGRAM WAS ESTABLISHED IN-HOUSE TO AUGMENT THE CAPABILITIES OFFERED BY NOAP IN SUPPORT OF TEST AND EVALUATION EFFORTS. THE FERROGRAPH MEASURES THE DENSITY OF LARGE AND SMALL PARTICLES IN A FIXED QUANTITY OF OIL AND ALSO HAS THE

PAGE TWO RUEBRDA444Ø UNCLAS E F T O
CAPABILITY TO GENERATE SLIDES OF PARTICLES FOR MICROSCOPIC EXAMINATION.
2. ONE OF THE ENGINES BEING MONITORED BY THE FERROGRAPH WAS J52-P-4Ø8 S/N 6783Ø1 INSTALLED IN A-4M BUNO 158148. A HISTORY OF THE DATA COLLECTED DURING THE MONITORING EFFORT IS AS FOLLOWS:

			PARTICLE DENSITY INDEX			
DATE	O/H HOURS	OIL HOURS	LARGE	SMALL	SAMPLE	REMARKS
8-22-75	423	128	1.8	2.5	1	*1
9-12-75	455	16Ø	6.8	3.9	4	*1
1Ø-1Ø-75	47Ø	2	5.Ø	1.7	5	*2
12-2-75	546	73	6.5	6.1	11	*1
12-2-75	546.5	.5	4.3	.8	1Ø	*2
12-16-75	537	41	1ØØ.7	6.8	26	*3

*1 OIL DARK
*2 OIL CHANGED
*3 A/C GROUNDED FOR ENGINE REMOVAL

NOAP SAMPLES TAKEN CONCURRENTLY WITH THE FERROGRAPH SAMPLES WERE ALL NORMAL. AS A RESULT OF THE CONTINUED INCREASE IN BOTH LARGE AND SMALL PARTICLES THE ENGINE WAS REMOVED AND REF A REQUESTED A DIR TO DETERMINE THE SOURCE OF THE PARTICLES. THE ENGINE WAS ASSIGNED CONTROL NO. JAX-152-214-5Ø AND THE DIR WAS CONDUCTED BY NARFJAX. REF B REPORTED

PAGE 1 OF 2
172ØØØZ MAR 76

EXHIBIT A-3

C O P Y

THE RESULTS OF THE INVESTIGATION. THE RESULTS OF THE DIR ARE SUMMARIZED AS FOLLOWS:

A. THE MAIN OIL PUMP (P/N 679698), THE NO4-1/2 AND 5 BEARING OIL PUMP (P/N 54Ø123) AND THE NO6 BEARING SCAVENGE PUMP (P/N 581188Ø) ALL SHOWED EVIDENCE OF SCORING OF GEARS AND HOUSING.

B. BRIGHT METAL CONTAMINATION WAS VISIBLE IN THE OIL THROUGHOUT THE SYSTEM.

C. BOTH THE NO4-1/2 BEARING P/N 493783 AND THE NO5 BEARING P/N 363169 WERE BOTH DAMAGED BEYOND USE. FAILURE OF NO5 BEARING WAS IMMINENT.

D. THE METAL CONTAMINATION DETECTED BY THE FERROGRAPH RESULTED FROM FAILURES OF THE MAIL OIL PUMP DUE TO MISALIGNMENT OF THE DRIVE SPUR GEAR SHAFT. ALL OTHER DAMAGE NOTED IN THE OIL SYSTEM WAS SUBSEQUENT AND DUE TO THE MAIN OIL PUMP FAILURE.

E. NOAP LAB TESTS OF OIL SAMPLES TAKEN FROM ENGINES AT NARF JAX REVEALED NO ABNORMALITY.

3. AS A RESULT OF THE SUCCESS OF THE FERROGRAPH IN DETECTING ENGINE OIL CONTAMINATION, WHICH WAS NOT DETECTED BY NOAP, THE NATC IN-HOUSE PROGRAM HAS BEEN EXPANDED TO MONITOR OTHER ENGINES AND COMPONENTS. BASED UPON THE LIMITED DATA OBTAINED TO DATE, IT IS NOT KNOWN WHETHER

PAGE FOUR RUEBRDA444Ø UNCLAS E F T O

THE FERROGRAPH WOULD BE AN EFFECTIVE TOOL FOR EARLY DETECTION OF OIL CONTAMINATION AND/OR ENGINE ACCESSORY ABNORMAL WEAR. HOWEVER, IN THIS ONE INSTANCE, THE FERROGRAPH WAS EFFECTIVE IN DETECTING A POTENTIAL BEARING/ENGINE FAILURE PRIOR TO ANY INDICATION OF FAILURE WITHIN NOAP.

4. IT IS RECOMMENDED THAT DEVELOPMENTAL ASSIST PROGRAM BE ESTABLISHED AT NAVAIRTESTCEN CONCURRENT WITH THE NAVAIRENGCEN DEVELOPMENTAL PROGRAM. THE COMPLETE SPECTRUM OF OPERATIONAL A/C AND ENGINES AT NAVAIRTESTCEN WOULD PROVIDE A WIDE DATA BASE FOR DETERMINING FERROGRAPH OIL ANALYSIS POTENTIAL AND APPLICATIONS AS AN AVIATION MAINTENANCE TOOL.

BT ORIG: SA ACT: AIMD FINAL PAGE OF 2
#444Ø COPY TO: SY RW AT 172ØØØZ MAR 76
TOD: Ø112Z/18MAR76/WE/EP/RO....SSN4445

EXHIBIT A-3 (continued)

APPENDIX B

ACTUAL PHOTOGRAPHS OF WEAR PARTICLES AND THEIR ORIGIN IN A J52 ENGINE

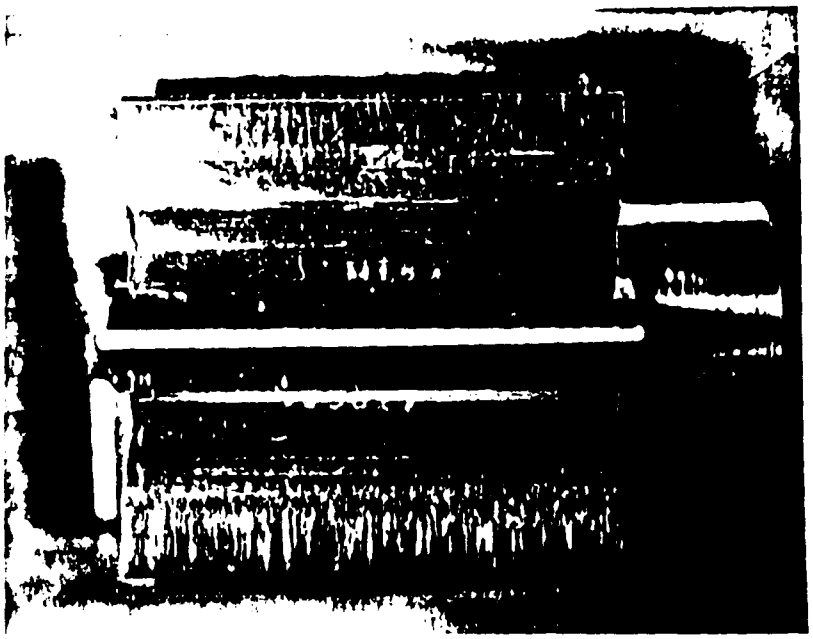

Figure 1 shows the drive spur gear, P/N 505827, which was removed from the main oil pump. It was lightly scored on both journals and severely scored on the impeller vane edges. The misalignment of the drive spur gear shaft caused this damage and resulted in the failure of the main oil pump and subsequent removal of the engine J52-P-408, S/N 678301. Note the heavy scoring marks at the bottom of the picture.

FIGURE B-1

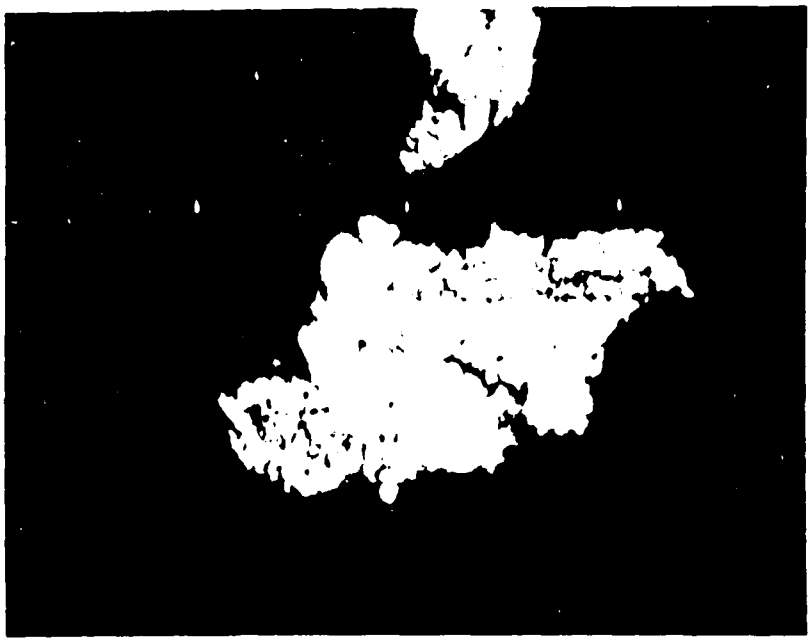

Figure 2 shows one of the large pieces of metal in the engine oil which was identified by the ferrograph. This particle was approximately 70 microns long and was probably from either the housing or the impeller vane edges.

FIGURE B-2

Figure 3 is a large piece of cutting wear found in the oil of the engine. Cutting wear occurs when part of a surface operates on another surface, like a microscopic lathe tool. This type of wear particle often occurs in large numbers immediately prior to failure.

FIGURE B-3

APPENDIX C

PARTICLE DENSITY ON FERROGRAPH SLIDES

The following graphs show the particle density distribution on four successive ferrograph slides. These slides were made from samples taken from a JT8D engine being tested at the Naval Air Propulsion Test Center. A ball bearing in the after-burner fuel pump of this engine ultimately failed completely. The size of the particles increases from the 10 mm position on the slide to the 50-60 mm area which is the area where the oil is first delivered to the slide.

There are several points of interest to be seen in these curves. First, the tremendous difference between the density values of samples K-9 and K-11 indicates a severe wear condition proceeding at a fairly rapid pace. The increase in the density of large particles is also noteworthy, especially the large jump between K-11 and K-14. This size jump is almost always indicative of imminent failure. The curve marked FAILURE is from a sample taken just after the engine had failed. The NOAP values on each curve indicate a trend toward failure. The low ferrograph readings in this sample are probably a result of the pump in which the bearing was located being shut down during part of the engine operation. The oil was not changed between samples K-9 and K-14; however, it was changed twice between K-14 and failure. Oil was added between every sample. The fact that the density readings for the small particles stayed fairly low, while the large particle densities increased rapidly is also indicative of bearing failure.

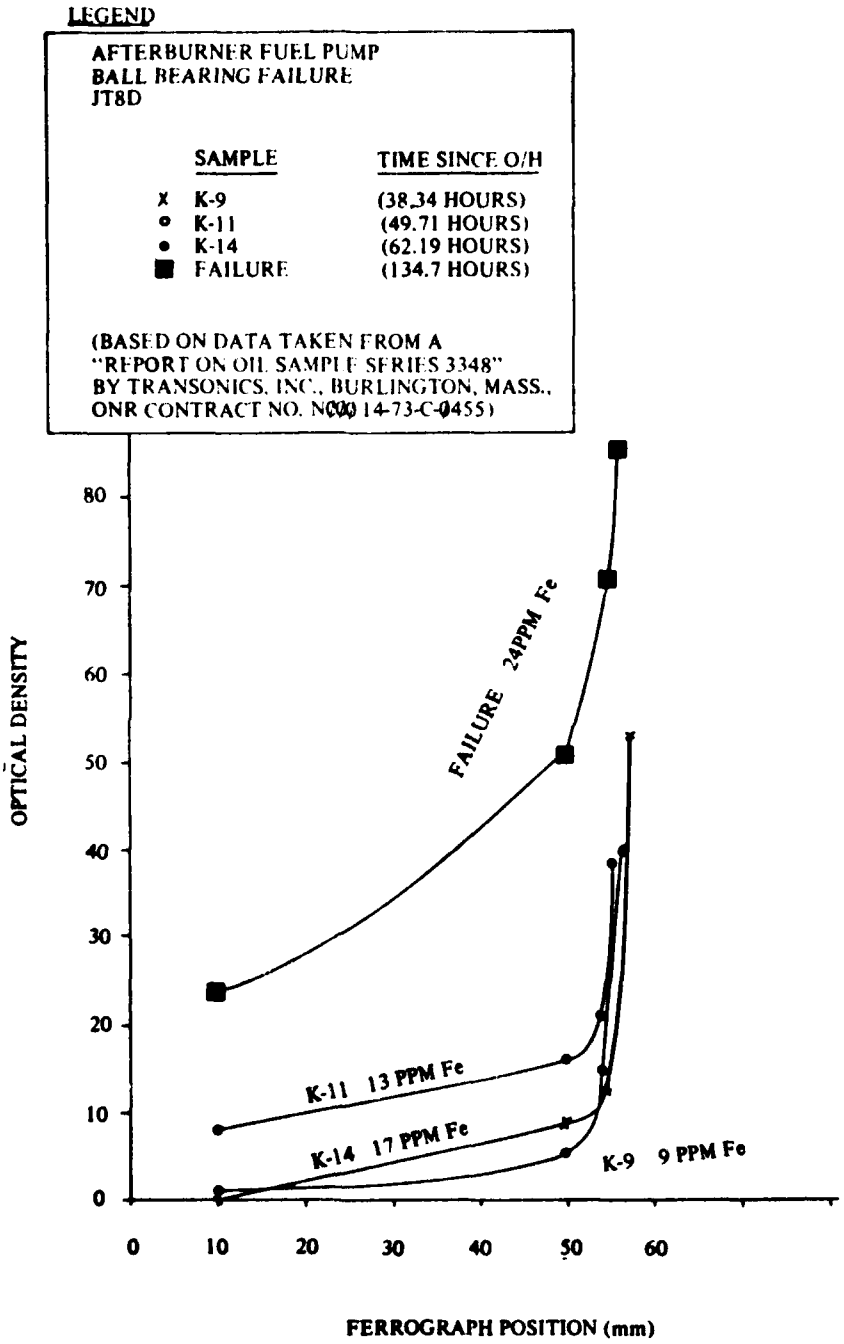
LEGEND
AFTERBURNER FUEL PUMP
BALL BEARING FAILURE
JT8D
SAMPLE
TIME SINCE O/H
K-9
(38.34 HOURS)
K-11
(49.71 HOURS)
K-14
(62.19 HOURS)
FAILURE
(134.7 HOURS)
(BASED ON DATA TAKEN FROM A
"REPORT ON OIL SAMPLE SERIES 3348"
BY TRANSONICS, INC., BURLINGTON, MASS.,
ONR CONTRACT NO. N00014-73-C-0455)
OPTICAL DENSITY
0
10
20
30
40
50
60
70
80
FAILURE 24PPM Fe
K-11 13 PPM Fe
K-14 17 PPM Fe
K-9 9 PPM Fe
0
10
20
30
40
50
60
FERROGRAPH POSITION (mm)

FIGURE C-1

APPENDIX D

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